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Walmsley, Anthony

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# Ultrasonics in dentistry

A. D. Walmsley *

*School of Dentistry, University of Birmingham, Birmingham, United Kingdom*

**Abstract**

Ultrasonic instruments have been used in dentistry since the 1950's. Initially they were used to cut teeth but very quickly they became established as an ultrasonic scaler which was used to remove deposits from the hard tissues of the tooth. This enabled the soft tissues around the tooth to return to health. The ultrasonic vibrations are generated in a thin metal probe and it is the working tip that is the active component of the instrument. Scanning laser vibrometry has shown that there is much variability in their movement which is related to the shape and cross sectional shape of the probe. The working instrument will also generate cavitation and microstreaming in the associated cooling water. This can be mapped out along the length of the instrument indicating which are the active areas. Ultrasonics has also found use for cleaning often inaccessible or different surfaces including root canal treatment and dental titanium implants. The use of ultrasonics to cut bone during different surgical techniques shows considerable promise. More research is indicated to determine how to maximize the efficiency of such instruments so that they are more clinically effective.

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## 1. Introduction

The tooth is prone to attack from bacteria, which forms on the surface of the hard dental tissues. This living biofilm is known as dental plaque. Over time the biofilm forms a tenacious deposit on the tooth that may also undergo mineralization leading to calcification. This is called calculus. Such biofilms may also form inside the tooth and require removal to prevent infection at the point where the root communicates with the body. Such infection may lead to abscess formation and other inflammation of the tissues. Whilst many procedures to clean the

* Corresponding author: A. Walmsley
*E-mail address:* a.d.walmsley@bham.ac.uk

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teeth may be done with hand instrumentation, the process can be achieved much quicker and with less work when using ultrasonic vibrations. This is one of the reasons why ultrasonic instruments are so popular with clinicians.

The ultrasonic instruments used in dentistry work at frequencies of 25 to 40 kHz. They were first introduced as a drill but then adapted as a scaling instrument used to clean deposits from the teeth (Lea and Walmsley, 2009). Such deposits are comprised of bacterial biofilms, which may or not be calcified. The vibrations transferred to a steel probe are used to physically remove them from the tooth. Such action also has the potential to damage tooth structure if the instrument is not used correctly. The instruments present as either a magnetostrictive or piezoelectric generator with a series of interchangeable probes fashioned in the form of dental hand instrument. It is the working tip that is used to remove the deposits from the tooth. The shapes of the probes are often curved which allows the working tip to negotiate difficult to reach places around or inside the tooth.

Figure 1. Clinical use of ultrasonic scaler

## 2. The working instrument

### *2.1 Mechanical Action of the ultrasonic scaler*

The ultrasonic scaler works mainly in a 'chipping' action, mechanically removing the deposits from the teeth. This removal is from the longitudinal chipping motion and rapid movement of the tip. This is seen as the primary method of action. During use a flow of cooling water is passed over the tip, which acts as an irrigant removing debris form the area. Within the water biophysical effects such as cavitation and acoustic microstreaming will arise which may prove useful in the cleaning process. Until recently most authorities claimed differences between magnetostrictive and piezoelectric generators leading to differences in the movement of the scaling tips. Using scanning laser vibrometry, it has now been shown that the movement of such tips is elliptical in nature and this is seen whether the tips are loaded or unloaded. The magnitude of this movement may differ between classes of instruments and it is the lack of standardization that has been highlighted (Lea et al., 2009a; Lea and Landini, 2010). It is known that different tips powered by different power generators show variation in either the unloaded (Lea at al., 2003a) or loaded (Lea at al., 2003b) situation. It is also possible to measure the vibration in 3D where the vibration picture is built up with the use of 3 scanning heads of SLV (Lea and Landini, 2010). The elliptical motion of all ultrasonic scalers is an important concept for researchers and clinicians. For researchers it means a change in thinking on how in vitro root surface investigations are evaluated. During use the ultrasonic scaler will not only remove the deposits but it will also partially impact into the tooth surface. Any defects produced are directly related to the shape and cross section of the tip. The elliptical motion of the tip will produce some damage which will be most pronounced if the tip of the instrument is allowed to dwell in one position. Clinicians should be made aware of the motion and at all times orientate the body of the probe parallel to the surface of the tooth to minimize damage.

There was initial apprehension over the use of ultrasonic scalers below the gumline. As the clinician is not able to view the oscillating tip then there may be increased root surface damage. Currently, there is general agreement in the literature that hand instrumentation may lead to more loss of root substance than ultrasonic instrumentation, irrespective of the study design (Walmsley et al., 2008).

Ultrasonic scalers have their own irrigation mechanism, which is related to the associated water supply. This is primarily needed to cool the heat generated from the rapid movement of the tip. The flow of water removes loosely attached plaque and dead bacteria from the tooth surface. It also improves clinician visibility by flushing debris from the pocket, and contributes to occurrence of cavitation and acoustic microstreaming in the water. There have been various chemical additives added to the water supply with the aim of increasing the effectiveness of the ultrasonic scaling but clinical trials have so far not shown any evidence that this provides any advantage (Lea et al., 2009b).

*2.2 Cavitation and acoustic mircostreaming*

The working ultrasonic scaler generates biophysical forces around the oscillating tip (Figure 2) which have the potential to be bactericidal. The phenomenon of cavitation results when the water supply meets the vibrating tip and forms minute bubbles (Lea et al., 2005). The bubbles grow in size, then collapse inward (implode), releasing a burst of energy.

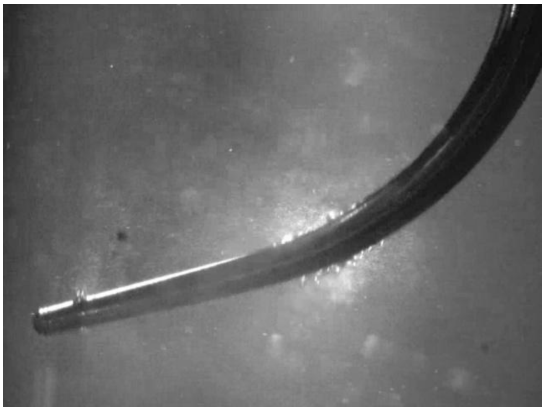

Figure 2. A frame from a video showing intense activity at the bend of the probe with some bubble formation near to the tip of the instrument.

This burst of energy has the potential to disrupt the cell walls of bacteria. Once the cell wall is disrupted, the bacteria are destroyed (Felver et al., 2009; Baehni et al., 1992). Most pathogenic bacteria, spirochete and motile rods, can be reduced to a presence of 0.1% (from an initial concentration of 50% in the study population) after ultrasonic scaling. A sharp decline was observed after 10 seconds and the spirochete population was nearly undetectable after 60 seconds.

Acoustic microstreaming is characterized by the generation of shear forces around the probe immersed in water. Both the cavitation and streaming forces will result in an acoustic turbulence that not only removes the attached deposits but also will break up the biofilm. This is an under researched concept and has the potential to enhance the working scaler. Early work demonstrated this potential when it was shown that water coolant that is flowing over the probe and then onto the tooth surface will clean the surface as the water flows in front of it. In Figure 2 the main occurrence of the cavitational activity occurs at the curve of the probe whilst a smaller amount takes place at the working tip. Research efforts are directed to enhancing the cavitation at the working tip where it will assist in the cleaning process.

## 3. Endodosonics

The internal structure of the tooth is known as the pulp and this may become infected if there is decay in the hard tissues of the tooth (enamel and dentine). Any breach allows the bacteria to infect the pulp and this will lead to pain and swelling with subsequent loss of the tooth if abscess formation results. The aim of root canal treatment is to remove the infected dental pulp and then produce a seal that will prevent the ingress of further bacteria. This removal may be undertaken with hand files and a suitable disinfectant such as sodium hypochlorite. The anatomy of the root canal is extremely complex and bacteria may remain in the canal. Often they are inaccessible to traditional hand instruments that are in the form of file used to cut the infected dentine and allow its removal.

The use of an ultrasonically activated instrument will produce both cavitation and streaming and enhance the use of any disinfecting fluid introduced into the root canal. The use of ultrasonics in the field of endodontics is termed "endosonics" and the procedure that has been developed is known as passive ultrasonic irrigation (PUI) technique. This is both popular and effective in removing any remaining biofilm in the root canal (Van der Sluis and Wu, 2005).

A key factor in providing the energy to produce the cavitation and acoustic microstreaming that allows the PUI to be effective is the motion of the endodontic file. The characteristic file motion has been assessed using laser vibrometry (Lea et al., 2004). Previous work indicated that file motion comprised a series of nodes and antinodes (Van der Sluis and Wu, 2005). However using both 2D and 3D SLV the movement of two files of differing taper, thickness and length were performed in air with a flow of water passed over them. The files evaluated were #10 and #30 files (27mm and 31mm) and are the designs commonly used clinically. They were powered by a piezoelectric generator (MiniMaster – EMS, Nyon, Switzerland), which operates at a frequency of 30kHz. Files were inserted into water bath so that the whole length of the file was immersed.

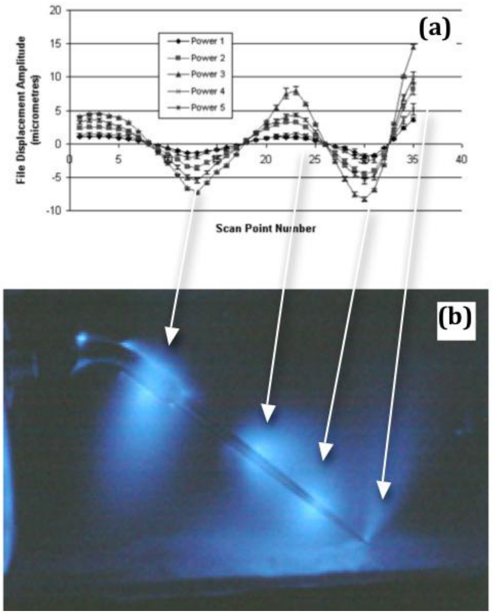


Figure 3. Correlation of (a) SLV amplitude measurements with (b) cavitation activity detected by chemiluminescence

It was found that initially increasing the power led to a similar increase in file displacement. However the vibration underwent a 'flattening' at higher powers (Lea et al., 2010a). Such changes in the file oscillation may lead to variations in the efficacy of the PUI clinically and merits further investigation. It appears that more work is required on the design of the files to maximize their oscillation at higher generator settings.

Cavitation occurring around the files has been mapped by monitoring sonoluminescence from luminol solution with different endosonic tips (Lea et al., 2010b).

Comparison between the streaming pattern inside the root canal and in the free field shows the importance of the confinement of the root canal on the acoustic streaming. The results give new insight into the role of acoustic streaming for the cleaning of root canals. Different tip designs resulted in different power outputs which further influence the vibration movement of the tips, cavitation activity and the rate of degrading of compounds such as Rhodamine B used to monitor such forces. Correlation was obtained between cavitation activity, SLV and the cleaning efficiency. Overall, the SP 1 tip which has a broader shape appears to be most effective tip design of those investigated. Therefore there is a strong relationship between the total energy transferred to the tip and the shape of the tip on cavitation production. Work is ongoing to correlate such oscillations with cavitation occurrence.

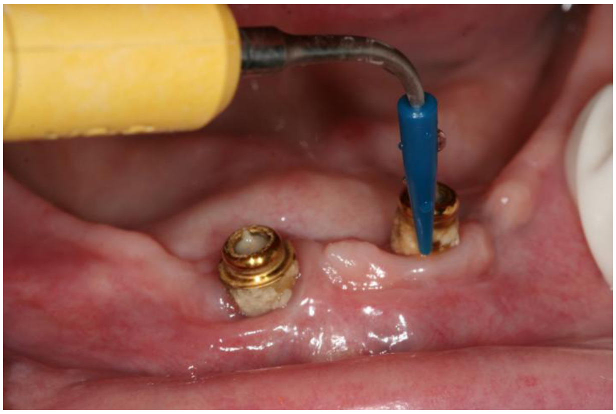

Figure 4. A plastic covered metal ultrasonic probe being used to clean titanium dental implants

## 4. Cleansing of titanium surfaces

There is an increasing use of titanium implants which are used as a replacement for teeth. In a similar manner to teeth, bacterial biofilm may attach to the titanium surfaces leading to further infection and inflammation of the surrounding dental soft and hard tissues. Considering the cost invested in such techniques then preventing loss of the artificial tooth has become an important objective. However cleaning the surfaces with metal instruments may lead to damage of the specialized titanium implant, leading to further biofilm growth on the roughened surface.

Various instruments have been designed and the material of construction has included stainless steel, titanium and hardened plastic. The ability of the ultrasonic scaler to clean the surfaces has generated interest. Work has investigated the vibration patterns of 2 ultrasonic scaler probe designs. One was a traditional metal probe based on the ultrasonic scaler described previously. The alternative approach was using a plastic coated probe work at ultrasonic frequencies. Scanning electron microscopy shows that whilst the plastic coated instrument does not cause the same indentations on the implant surface as the stainless steel probe, there is evidence that the "rubbing" of the plastic leads to its heating with particles of melted plastic on the surface (Mann et al., 2011). More damage to the titanium implant surface is seen if high loads are applied and at high power settings. Therefore whilst ultrasonics may be an attractive alternative to cleaning such sophisticated surfaces, it is not a viable proposition in its present form. The area shows potential for further research.

## 5. Piezosurgery

The original idea of using an ultrasonic tool to cut hard tissues such as teeth may have been superseded by the use of high-speed rotary drills but the idea did not totally disappear. There has been recent interest in the use of ultrasonics to cut bone in surgical applications (Parmar at al., 2011). These ultrasonic probes are powered by piezoelectric generators leading to the term "Piezosurgery". Whilst there have been several enthusiastic clinical reports on the use of such devices there has been few reports of the oscillatory behavior of these Piezosurgery Bone Cutting Tips. Studies have looked at the oscillation of such probes under different operating conditions and to correlate the vibration patterns with the bone defects that are produced.

A Piezosurgery Ultrasound Unit (Mectron, Italy) was used with the 3 Cutting Modes available which are Cortical, Spongious and Special settings. A commonly used cutting tip was assessed and shown to have similar elliptical pattern of oscillation to its ultrasonic scaler cousin. Work shows that light pressure is need to maximize the bone cutting process and if the loading reaches 200g then the oscillation can "stall". Whilst the instruments are designed to cut the harder outer cortical bone, the trabecular inner bone structure can lead to damping down the oscillations.

This area of ultrasonics use merits further investigation as further research is required to look at the temperature changes during cutting, alterations to the organic/inorganic components within the bone, changes to osteoblast viability/vitality and quantity/quality of debris produced.


Figure 5. A plastic covered metal ultrasonic probe being used to clean

## 6. Clinical Relevance

Ultrasonics is firmly established as a routine clinical procedure in dentistry. Whilst the major use of the instrument relies on the metal probe – tooth contact to achieve the result of removing deposits off the tooth surface, there is a contribution from cavitation and acoustic microstreaming occurring in the water supply. There have also been new and exciting developments in other specialties in dentistry for cleaning difficult to access areas (Root Canal Treatment) or new surfaces such as dental implants. The use of the instrument to cut bone also opens up new opportunities.

One area of further research that shows merit is using the phenomenon of cavitation and acoustic microstreaming to break up bacterial biofilms.

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